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PROTECTION OF SUBSIDING WATER-FRONT PROPERTIES

by Robert R. Shoemaker, M. ASCE

WATERWAYS DIVISION

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PROTECTION OF SUBSIDING WATERFRONT PROPERTIES

Robert R. Shoemaker,[1] M. ASCE

SYNOPSIS

There are occasional land subsidence phenomena which require extensive remedial work because of their location and the values of the properties affected. The area discussed herein is unique in its extent, its magnitude of settlement and in the value of superimposed development of real properties. The magnitude and types of problems which arise and some of the methods of meeting these problems are presented.

INTRODUCTION

In the southern part of Los Angeles County, contiguous to and beneath San Pedro Bay, which is an arm of the Pacific Ocean, and extending over several incorporated and unincorporated areas, there has developed over the past fifteen years a very extensive and deep-seated land subsidence accompanied by horizontal movements. The nature and causes of this subsidence have been discussed in various mediums heretofore in its earlier stages. The initial public discussion of a technical nature is believed to have been published in 1949.[2]

A large number of unpublished reports both preceded and followed the article by Gilluly and Grant. Notable among these was a symposium presented before the Convention of ASCE at Los Angeles, California, April 28, 1950.[3]

Some of the discussion at this symposium was extensively reported, but was not published. By 1949 the true seriousness of the phenomenon was becoming recognized.

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1. Chief Harbor Engr., Port of Long Beach, Calif.; Chairman of Technical Committee, Harbor Area Subsidence.
2. "Subsidence in the Long Beach Harbor Area, California," by James Gilluly and U. S. Grant—Vol. 60, pp. 461-529, 1949.—Bulletin of the Geological Society of America.
3. Papers presented before Convention of American Society of Civil Engineers, Los Angeles, California, April 28, 1950, in "Special Session on Subsidence." Authors:—C. L. Vickers, Assistant Harbor Engineer, Port of Long Beach; J. H. Davies, M. ASCE (deceased); Charles R. Dodson, Petroleum Engineer; U. S. Grant, M. ASCE, Professor of Geology, U.C.L.A.; R. Howard Annin, Structural Engineer, Los Angeles, California; E. H. Harlow, M. ASCE, New York City; L. C. Coxe, Commander, U. S. Navy; W. L. Chadwick, M. ASCE, Southern California Edison Company, Los Angeles, California; Jan Law, Petroleum Engineer, Long Beach, California.

Current Status

The subsidence had progressed by late 1954 to an amount and extent exceeding all early predictions of its magnitude and it now presents a difficult, expensive and complicated problem of effectively accomplishing coordinating and financing needed remedial work. However, the overall economics of the affected surface area dictate that every possible effort be devoted to corrective measures.

This particular land subsidence has been attributed by most careful students and investigators of the subject, principally to the reduction of fluid pressures in certain and possibly all of the producing zones of the Wilmington (California) Oil Field. Inasmuch as oil and gas have each been produced in this field as usual in the process of producing oil, it is concluded that each withdrawal exerts its respective influence in altering the virgin soil characteristics and subsurface pressures.

The subsidence is occurring in an area which is intensively developed with highly valued surface and subsurface improvements which are extremely important to the economy of the immediate area and its surroundings. The adverse effects are greatest in both uplands and filled submerged land areas very close to San Pedro Bay where the ground elevation prior to land subsidence was only a small height above extreme high tides of the Pacific Ocean. These lands, now mostly below high tides, are the most subject to flooding. Segments of Los Angeles Harbor, all of the developed portions of the Port of Long Beach and the lower reaches and outlet of the Los Angeles River—principal stream of Los Angeles County, now converted and realigned into a flood control channel—are located within the subsiding area.

To illustrate the extent of the potential flooding possibilities, the total existing waterfrontage which had subsided in excess of 2 feet and up to a maximum of 20 feet by late 1954 is approximately 30 miles. In addition to this 30 miles, there are 4 existing miles of waterfront which are in a more slowly sinking area—principally southwest of the elliptical shaped subsidence bowl—and some 3 miles which are expected to subside rather large amounts—principally to the east of the present large disturbances. Potential long range future expansion of the Port and of oil producing sites will add from 8 to 12 miles of waterfront in subsiding areas. This latter frontage presents much less difficulty in that with adequate knowledge full compensation for subsidence can be made at the time of development. A total of 50 miles of waterfrontage—existing and potential—is thus affected.

Figure 1 is an oblique air photograph taken in 1954 from a position looking northeasterly toward the principally affected area. Long Beach and the Santa Ana mountains lie in the background. The nature of shoreline development is clearly illustrated. Most of the affected shoreline is shown.

The rate of subsidence per annum varies a great deal as to time and place but is of such magnitude as to impose important time limits on planning, scheduling and constructing the remedial works.

Figure 2 illustrates with heavy lines the isobases of equal subsidence ranging from 2 feet to 20 feet, over a period from 1928 to August 1954.

Since changing rates of subsidence are a valuable planning and analysis tool, the rates are observed very carefully. Figure 3 shows the yearly rates for the period ending August 1954. The rate at the center of the subsidence bowl is shown as 1.6 feet per annum—a decline from the recent maximum of nearly 2.5 feet per annum at that point.

FIGURE 1 - AIR PHOTOGRAPH LOOKING SLIGHTLY NORTH OF EAST AND ILLUSTRATING CHARACTER OF AFFECTED SUBSIDING AREA

Each of some 250 bench marks are frequently checked and the rate of movement is sufficient for reasonable accuracy. Figure 4 illustrates a typical subsidence curve for one of the more rapidly moving bench marks. In this case the abscissa represent the years; the ordinate the cumulative feet of subsidence. Nearly 13 feet is shown for the total to 1954. Thirty feet is predicted at this point by one investigator.

Major Effects

In few instances was the original land or structure elevation adjacent to the waterfront more than 6.5 feet above the predicted extreme high tides. In many locations the freeboard above high tide was much less. The highest tides occurring in the area are predicted as 7.5 feet above mean lower low water and are comparatively free from excessive variations. Exceptions are occasionally known in that tides exceed predictions a foot or more as a result of offshore seasonal storms. These overages usually threaten to and may coincide with high tides. Conditions in the affected area are such that a strong earthquake might reduce some filled land elevations in significant amounts.

The occurrence of low, long period seismic tidal waves or Tsunamis[4] as a result of seismic disturbances in the North Pacific have been known to add substantially to the level of the adjacent bay waters for short rhythmic periods. Such occurrences, if coincident with normal high tides, would present serious

4. "The Tsunami of Nov. 4, 1952 as Recorded at Tide Stations." Special Publication No. 300, U. S. Dept. of Commerce, Coast and Geodetic Survey, Washington, D.C.

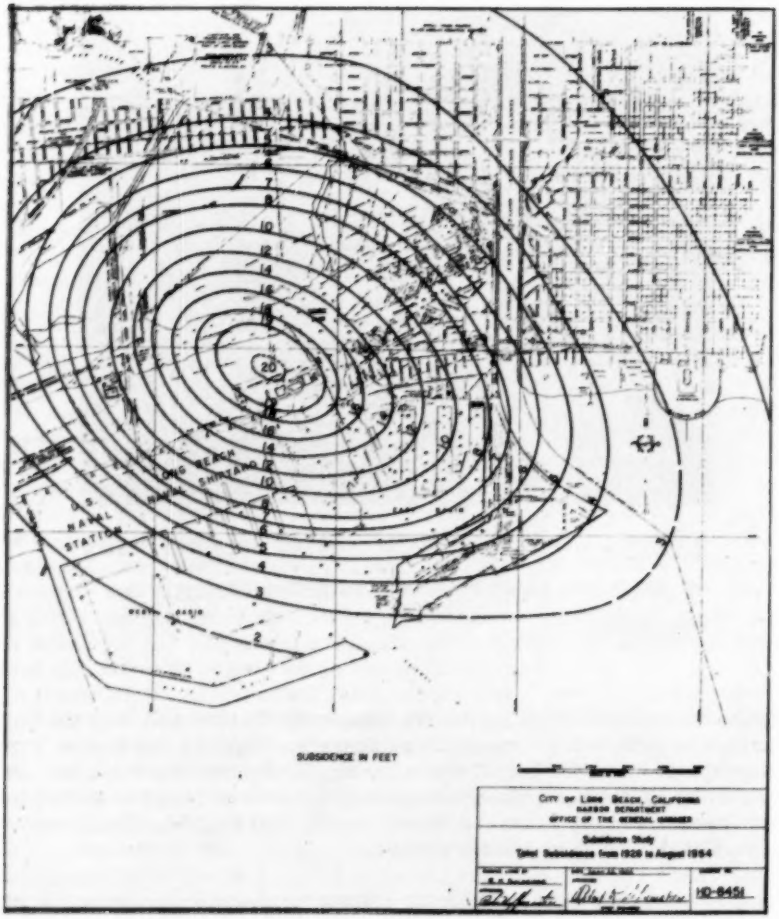

FIGURE 2 - SUBSIDENCE ISOBASES TO AUGUST 1954, SUPERIMPOSED ON PORTION OF HARBOR AREA

flooding hazards. The period of these tidal waves at the point in discussion has approximated 34 minutes and the height has been about 4 feet from trough to crest. Since the waves persist for 24 hours or more, they impose a definite hazard where levees are low or unstable.

Physical improvements in close proximity to the waterfront and at low elevations are valued in excess of five hundred million dollars, including some 2500 producing or salvageable oil wells with their many accessory structures. Back area developments not located immediately adjacent to the waterfront, but affected in other respects and in some instances subject to possible flooding, represent additional high valued investments.

Essentially all of the affected area is utilized for transportation, industry, commerce and oil. Thus the area is important to a very large population—in fact much of the population of the Pacific Southwest. Some of the subsiding

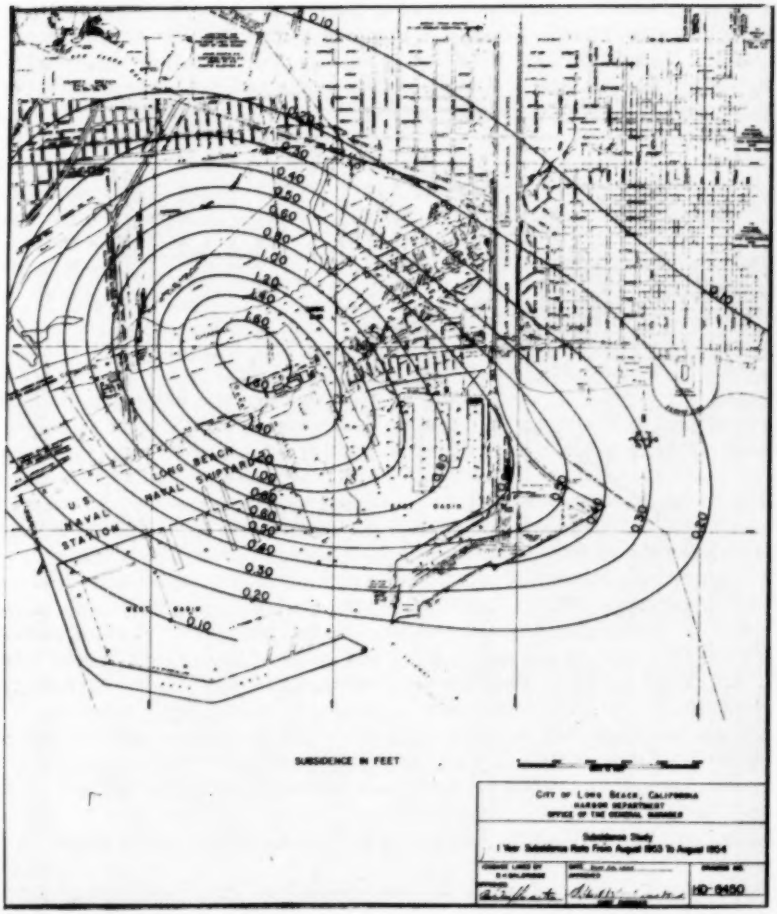

FIGURE 3 - LINES OF EQUAL ANNUAL SUBSIDENCE RATES FOR YEAR ENDING AUGUST 1954

area is beneath San Pedro Bay where the water merely becomes deeper. Much of it is beneath the waters of the channels, slips, basins and fairways of the harbors and beneath the flood control channel which serves to protect the adjacent lands. To the extent that it relieves certain dredging obligations it is an asset in these water areas.

By 1954 in excess of 2,000 acres of natural or artificially created industrial land which was above the level of high tide before subsidence, had settled well below that level or would have been below that level had it not been for remedial work theretofore accomplished.

The normal ground water table is about elevation plus 3.5 feet above mean lower low water, and inland areas below that elevation would naturally become brackish lakes even though protected from ocean tides. The great scope of the remedial program to compensate for subsidence can thus be seen.

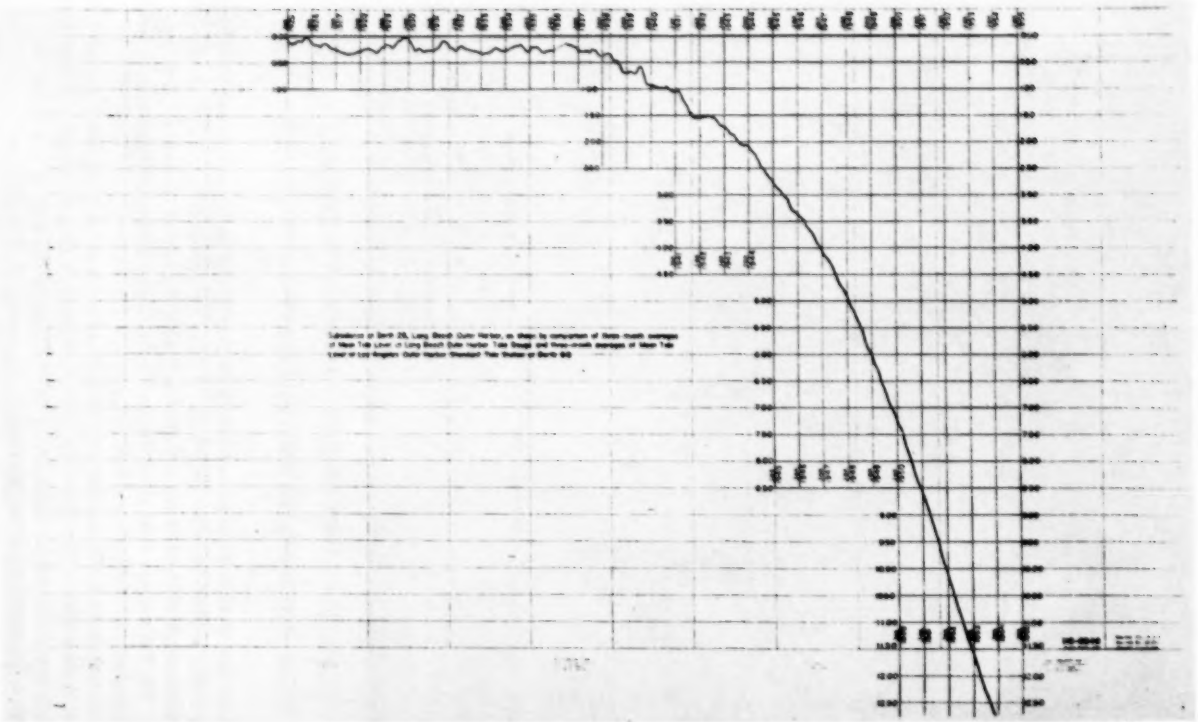

FIGURE 4 - CUMULATIVE SUBSIDENCE IN FEET TO 1954 AT BENCH MARK 700 NEAR CENTER OF AFFECTED AREA

The bowl of subsidence by August 1954 had become sufficiently large that the limits within which 2 feet or more of subsidence had occurred included over 14 square miles. The area shown within the roughly shaped ellipse defined by the 2-foot isobase on Figure 2 is about 6.0 miles along the major axis and nearly 4.0 miles along the minor axis. The volume of subsidence represented by the portion of the subsidence bowl within the 2-foot isobase is approximately 48 million cubic yards. If it were feasible to completely restore original land surfaces within this 2-foot mark to the levels which would have existed without subsidence, it would require some 40 million cubic yards of compacted earth fill.

Subsiding areas outside the 2-foot isobase are considerably greater than those within, as is the volume of subsidence. Since there is general subsidence of small magnitude in other nearby areas, it is difficult to define the exact limits of the area of influence of the phenomenon under discussion. For purposes of analysis of rates and prediction, however, this area of influence is estimated to approximate 52 square miles. As a result of analyses beyond the scope of this paper, the subsidence ellipse is expected in future years to elongate further to the southeast and to deepen at its center to approximately 30 to 32 feet by the year 1970.

In view of the deep seated compaction which is the origin of the trouble, generally agreed to be at depths of from 2,200 feet to 4,000 feet and more, the body of sediments acted upon by the forces of subsidence is a complicated three-dimensional body and there is a persistent but varying horizontal movement of all points on the surface toward the center of the subsiding bowl. It naturally follows that subsurface movements are also present.

The overall magnitude of these horizontal movements is at many points measured in feet and reduces substantially the surface areas within the boundary markers of large property holdings. The differential horizontal movement with which those planning surface remedial work or new construction work are presently concerned is the most important factor. Differential movements have in certain locations attained a magnitude of some 4 inches or more per 100 feet, or 0.33 per cent. It has been calculated that differential movements will probably attain magnitudes of as much as 6 inches per 100 feet or 0.50 per cent.

The elastic limit of all ordinary construction materials can therefore easily be exceeded, provided the design of the installation is of such nature as to permit the earth's forces to be transmitted to the structure. Great local concentrations of stress due to horizontal movement occur. Some areas experience compression, torsion and even reversals to tension. Other areas experience initial tension followed by compression. In instances, of which there have been at least three, where the capacity of subsurface strata to resist the subsurface shears is exceeded, these strata have failed suddenly in horizontal shear. Such failures distort or shear oil wells passing through the affected strata and also result in a readjustment of surface positions in limited areas.

Figure 5 is illustrative of the relative nature of horizontal forces actually measured in the area by repeated triangulation. There appear on this figure the subsidence isobases as of November 1951, and also the magnitude and direction of movement of several monuments. From each monument is shown by vector drawn to relative scale, the feet and bearing of the gross movement of that monument to the date of survey.

Differential vertical movement is also of major concern, especially since it attains an order of one foot or more in 400 feet.

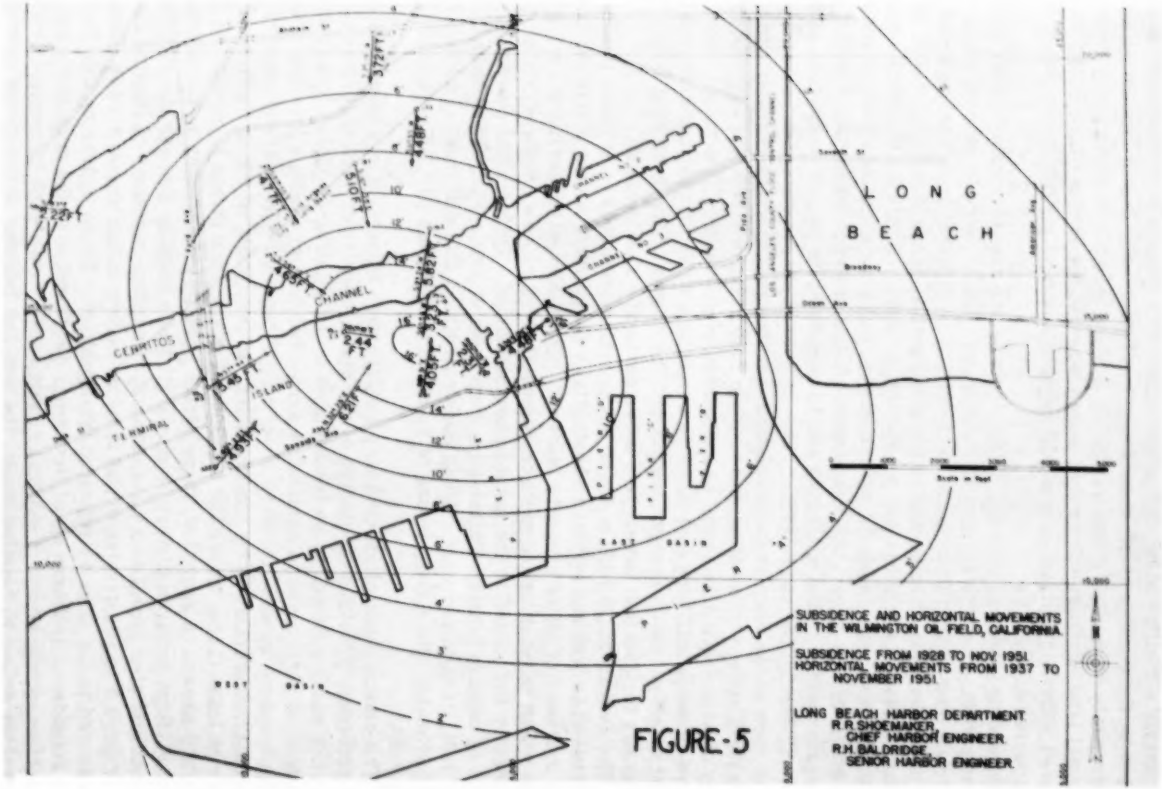
LONG
BEACH
CHANNEL
CERRITOS
ISLAND
EAST BASIN
WEST BASIN
SUBSIDENCE AND HORIZONTAL MOVEMENTS
IN THE WILMINGTON OIL FIELD, CALIFORNIA
SUBSIDENCE FROM 1928 TO NOV 1951
HORIZONTAL MOVEMENTS FROM 1937 TO
NOVEMBER 1951
LONG BEACH HARBOR DEPARTMENT
R.R. SHOEMAKER,
CHIEF HARBOR ENGINEER
R.H. BALDRIDGE,
SENIOR HARBOR ENGINEER

FIGURE-5

The variable but continued nature of these vertical and horizontal movements, combined with periodic changes in prediction as to the maximum movements to be expected and their timing, has complicated remedial work.

A further complication arises from the fact that most operating waterfront industries and port operating facilities should preferably not be established at excessive heights above harbor waters, and it is not always practicable to elevate structures to their full required height in one operation.

Up to 1954 the overall policy on remedial work dictated by events and good judgment had resulted in approximately the following status of corrective works.

1. Most remedial work had been purposely delayed or only partially accomplished if economically and practically possible to do so.

2. Such work as had been done had usually been so designed as to be a part of and to permit of further development of the same protective work in the future.

3. Most work had necessarily been so accomplished as to permit coordination with that of neighboring owners.

4. Coordination had been accomplished by simple processes. Construction permits clear through the Port of Long Beach Engineering Division, if the work is in Long Beach. Thus it is usually simple to determine the plans of others. In addition, five special subsidence committees, representative of the principal land owners of each of the five separate areas having common flooding problems, have been sponsored by the Port Engineering Division. These engineering committees meet periodically—usually monthly on days of extreme high tide—to study, discuss and report on the state of levee development. Questions of relative responsibility for work have been subordinated to the principal policy of cooperation. The engineering staffs and managements are quickly advised of any apprehensions of these committees.

5. Many areas nearing the hazard point had been left uncorrected. This policy was fixed in some cases by the desire of the owners to obtain the latest predictions and advices before initiating rehabilitation and in others by the necessity of maintaining current operations. Internal Revenue Department policies of questioning the tax deductions for remedial work in anticipation of future subsidence of privately-owned improvements being destroyed by subsidence have also delayed or determined the order of some activities.

6. Some form of actual rehabilitation in the form of partial, temporary or permanent physical barriers to flooding had already been accomplished along some 20 miles of waterfront.

7. Roughly, 40 millions of dollars properly chargeable to subsidence had been expended for surface operations by 1954. These expenditures had been borne principally by about 12 large public and private owners and their lessees. Lesser ownerships have usually been incidental beneficiaries of the protective works of others, but in many cases have also expended considerable sums.

8. Most remedial work has necessarily had an element of additions and betterments incorporated and for this reason the overall economy and utility of the area has continued to increase during the reconstruction period.

9. The magnitude of individual remedial projects was generally being increased because better defined trends of future subsidence were becoming available.

10. The general policy of delaying permanent remedial work where practicable has its limitations, and the period of intensive activity had started ascending toward a peak of construction work which should be attained during 1956 to 1958. In particular, the municipal port body must increase its program rapidly.

Every instance of remedial work represents some form of compromise, but with the overall program there can be no compromise. The many miles of waterfront are compacted into a very small area. The greatest single flow of flood waters in Southern California, with very rapid run-off, passes with high velocity through this compact subsiding area. Since the capacity of this flood channel is largely influenced by ocean level at its mouth, radical changes were necessary in the levees and bridge structures along the lower reaches of this stream.

An incidental benefit of the required removal of bridge structures which had become serious flood hazards is that in such compact areas there is no practicable method of replacement of the bridges which will not vastly improve the operations of the Harbor District by means of railroad and highway grade separations with consequent improved land transportation.

Also, because of the physical changes brought about by undertaking the bridge and access remedial work, it is necessary to acquire some 100 acres of privately-owned and developed properties which are damaged or occupied by these works. A limited amount of this acquisition will eventually further serve the functioning of the Port, aside from meeting the access needs.

The full import of the remedial program needed and being undertaken can best be portrayed by illustration.

Figure 6 again shows subsidence isobases to August 1954, but emphasizes the waterfront in heavy lines. In some areas these isobases almost parallel the waterfront and illustrate how a great deal of frontage can quickly become critical as the subsidence bowl spreads in area and deepens. Sections A, B and C, located on Figure 6, are shown on Figures 8 to 14, inclusive.

There have been many predictions as to the form and degree of total subsidence. Figure 7 is one of these predictions, with portions of the isobases omitted because they extend beyond the area over which the author has engineering responsibility. Sections A, B and C are also located on this figure. The author subscribes neither to this or any other single prediction on ultimate subsidence.

By comparing 1954 conditions of Figure 6 with the ultimate predictions of Figure 7, it will be noted that the effect of the transition would be to increase 1954 subsidence about 50 per cent in some areas near the center of the bowl, whereas in others it would be to increase subsidence some 600 per cent or more.

Figures 8, 9 and 10 have been grouped to illustrate the nature of the remedial problem. Each is a section along line A-A of Figure 7 which is nearly but not exactly the major axis of the subsidence bowl.

In Figure 8 is shown how, had no subsidence occurred, the water surface of the six waterways or channels intersected would be safely below the elevations of the adjacent land, piers and structures, which for convenience are indicated to be elevation plus 12 feet—about an average condition originally.

Figure 9 illustrates with vertical scale exaggerated the hypothetical condition that would have existed in 1954 along the same section line had not remedial work been done. As indicated, the area generally would have been beneath the ocean level and at the worst point would have been submerged 15.5 feet.

Figure 10 illustrates in heavy lines, with the same exaggeration of vertical scale, the more extensive of the remedial works being undertaken along this same alignment, and the manner in which these works exclude the ocean at each slip or basin and sometimes replace abandoned facilities. Some of these works are completed, others are under construction and some are yet to be undertaken.

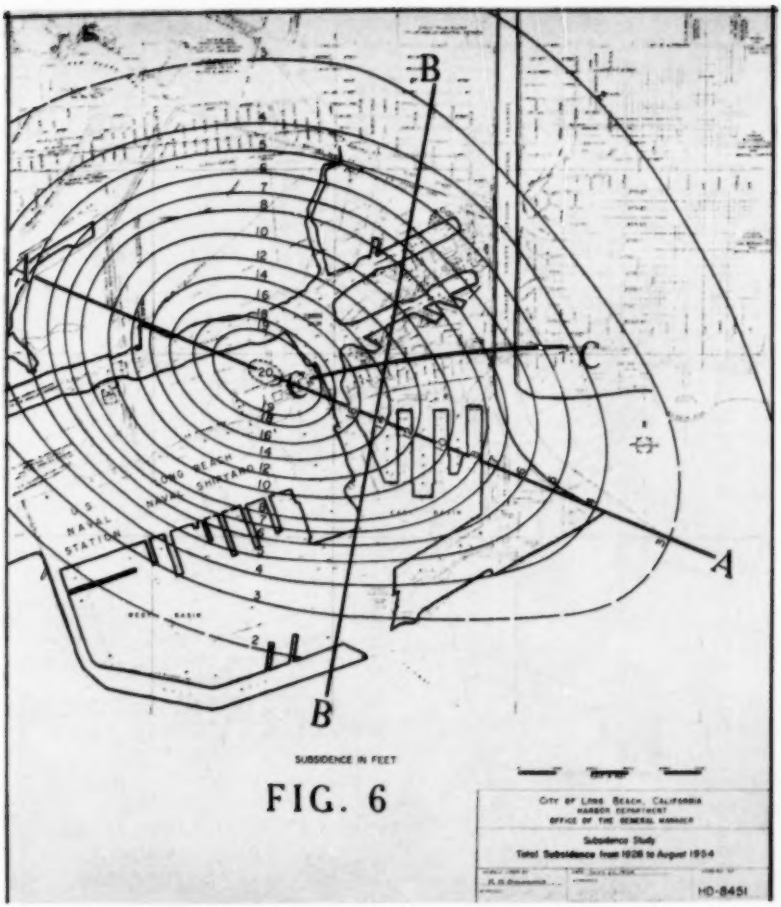

FIGURE 6 - WATERFRONTAGE EMPHASIZED

IN RELATION TO CURRENT SUBSIDENCE

The 1972 potential profile of subsidence is shown in dashed lines to indicate the probable need for further protective works before that date.

Figures 11, 12 and 13 illustrate the same series of conditions and periods along Section B-B as were described for Section A-A.

These sections further illustrate that without protective devices the large areas cut by Sections A-A and B-B would be completely submerged.

Figure 14 is a simplified section along Line C-C. This section depicts some of the more radical works as it is positioned along an east-west line which passes through a fully subdivided and developed business and industrial area, which also contains many privately owned oil wells and low grade housing for possibly 1,000 persons, all within a street pattern originally designed for a seaside resort. This area is practically surrounded and bordered on all four sides by waterways and is so situated that many important waterfront

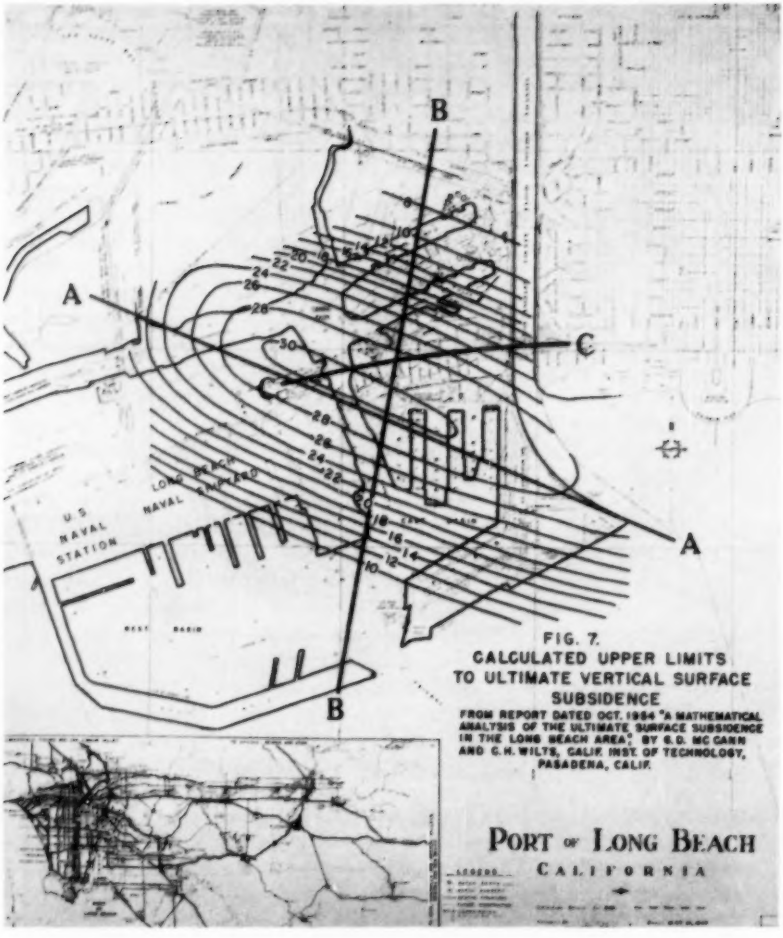

FIG. 7.
CALCULATED UPPER LIMITS TO ULTIMATE VERTICAL SURFACE SUBSIDENCE
FROM REPORT DATED OCT. 1954 "A MATHEMATICAL ANALYSIS OF THE ULTIMATE SURFACE SUBSIDENCE IN THE LONG BEACH AREA" BY G.D. MC CANN AND C.H. WILTS, CALIF. INST. OF TECHNOLOGY, PASADENA, CALIF.

facilities, such as a shipyard, industries, wharves, piers, bulkheads and quays, can only be reached and served by rail and truck transportation routes which pass through or skirt the area.

The waterfront remedial works which must serve to rehabilitate the operating port facilities must also exclude high tides for many years until indicated land raising operations are completed. Such waterfront works cannot function without adequate rail and highway approaches. These approaches in turn must be raised and rerouted and thus disturb all adjacent lands shown in section on Figure 14.

After a great deal of study, the municipal port body which owns most of the surrounding waterfrontage, determined upon a general land raising program which is designated by the new grade line on Figure 14. This land raising program necessarily requires close coordination in order to maintain all important operations at all times. Therefore even the final solution chosen will not completely eliminate the necessity for many temporary expedients and will take 6 to 10 years to accomplish.

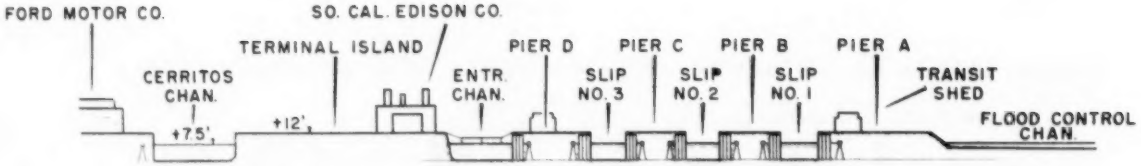

FIG. 8. SECTION A-A. 1954 - NO SUBSIDENCE OCCURRED.

FIG. 9. SECTION A-A. 1954 - NO REMEDIAL WORK ACCOMPLISHED.

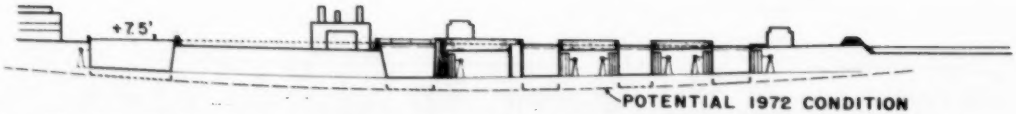

FIG. 10. SECTION A-A. 1954 - HEAVY PORTIONS REMEDIAL WORK.

COMPARATIVE SECTIONS SHOWING EFFECTS

OF SUBSIDENCE AND METHODS OF REMEDYING

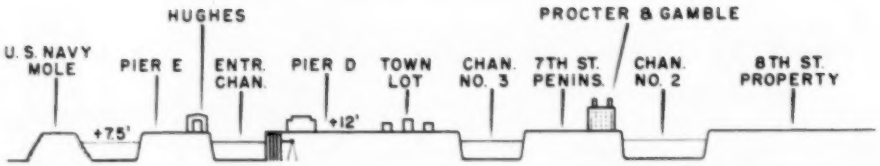

FIG 11. SECTION B-B. 1954 - NO SUBSIDENCE OCCURRED.

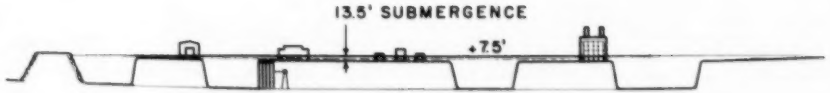

FIG. 12. SECTION B-B. 1954 - NO REMEDIAL WORK ACCOMPLISHED.

FIG. 13. SECTION B-B. 1954 - HEAVY PORTIONS REMEDIAL WORK.

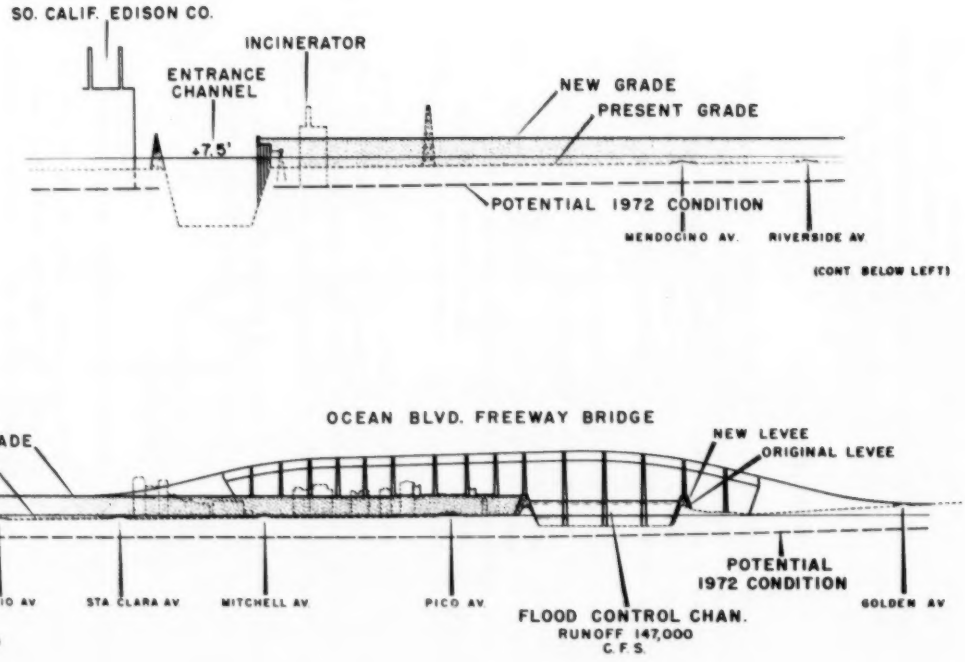

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FIG. 14. SECTION C-C. NORMAL TO FLOOD CONTROL.

THIS SECTION THROUGH HARBOR ENTRANCE CHANNEL, FLOOD CONTROL CHANNEL AND DEVELOPED PRIVATE LANDS SHOWS MANNER IN WHICH ENTIRE AREA WILL BE FILLED AND BRIDGES CONSTRUCTED TO OVERPASS STREETS AND TRACKS ON NEW FILL

The change in the Ocean Boulevard bridge and bridge approach is indicated. It is typical of the bridge problem which requires clearances to overpass both railroads and a fill. If left unfilled, some of the areas shown to be filled will be as much as 25 feet below high tide by 1972. There are areas 12 feet or more below high tide in 1954. The only protection which these low lying properties now have against flooding are waterfront bulkheads, seawalls and dikes of virtually every conceivable variety and local pumping and drainage systems. As the subsidence progresses, emergency measures for disposing of ground water, of waste water and of rain water and seepage must be installed.

Specific Remedies

To illustrate a few of the radically varying types of waterfront remedial works, several full cross-sections of construction changes are shown.

Figure 15 is an example of a quay wall of cyclopean concrete completed in 1954 to replace an old wharf which is shown by dotted lines at an elevation 16 feet lower. The older structure had become submerged and was no longer usable.

Figure 16 is another example. The original waterfront—(not shown in detail)—was plus 8.4 feet in 1949; would have been plus 2.4 feet in 1954; but was replaced with a circular cell bulkhead or quay to elevation 22 feet.

In Figure 17 is illustrated a section of waterfront originally protected with an anchored vertical steel sheet pile flexible bulkhead, shown in dotted lines, retaining a fill. Remedial measure, shown in full lines, was an adaptation which stabilized the bulkhead and also meets the needs of shipping at a higher elevation.

Figure 18 is illustrative of a temporary raising operation, varying from 2 to 4 feet. It is designed only to meet an emergency need to prevent flooding and extend the useful life of the old structure. One more emergency step is possible at this point. Thereafter a much greater elevation change will be made.

Figure 19 is illustrative of the general types of levees used in areas where current waterfront operations are not a factor. The cutoff cores reduce infiltration of sea water to a high degree.

Types of Remedies

A few of many different types of remedies are described as follows:

1. Simple truck-dumped earth fill dikes are constructed where danger of flooding is momentary (at periods of extreme high tide or surge) and back area conditions justify. The same procedure applies for temporary installations awaiting more permanent works.
2. Elaborately designed and consolidated earth levees with center cores of impermeable muds or clays are indicated and have been used where large land areas are used exclusively for oil production; where there is little or no habitation and where there are no waterfront industrial or port facilities. Such installations require extensive drainage and pumping facilities and/or well point systems to supplement the levees and present a steadily increasing pumping and drainage program within the protected areas.
3. Large scale filling of low areas to elevate them to heights calculated to remain above the elevation of high tide or of ground water are often used. In a comparatively virgin area, free of surface structures, this procedure is simple and ideal. There are few such areas. Where the intensity of surface

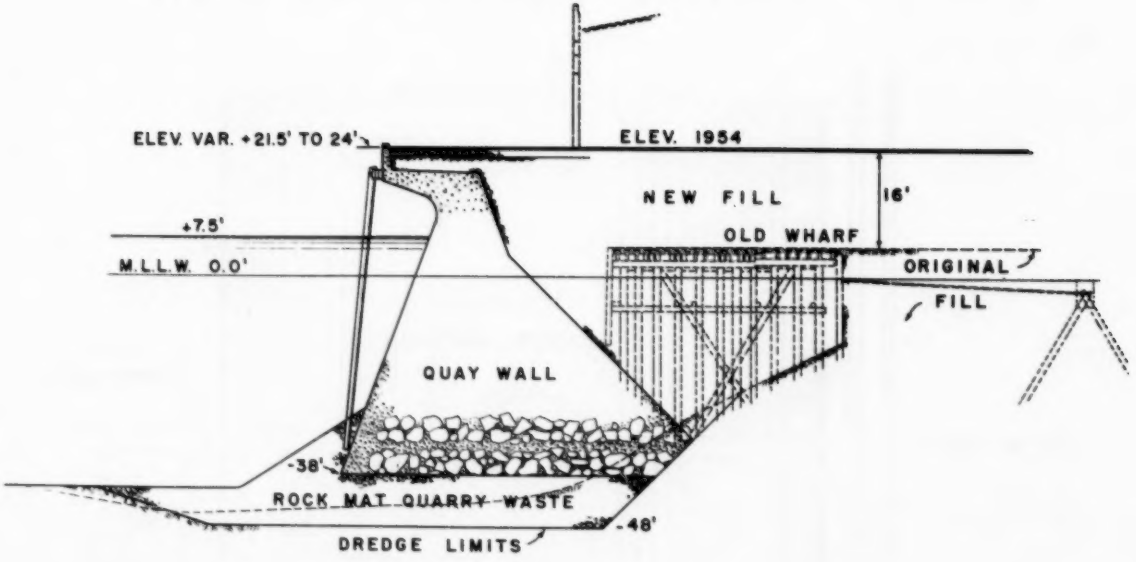

FIG. 15. QUAY WALL - PIER D.

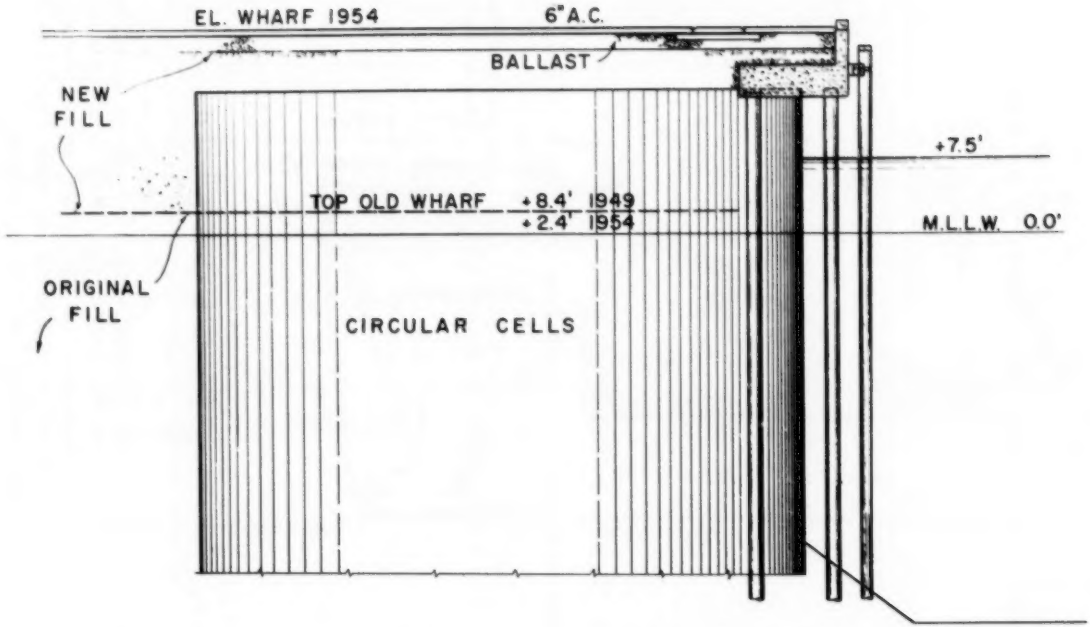

FIG. 16. CIRCULAR CELL BULKHEAD - PIER D.

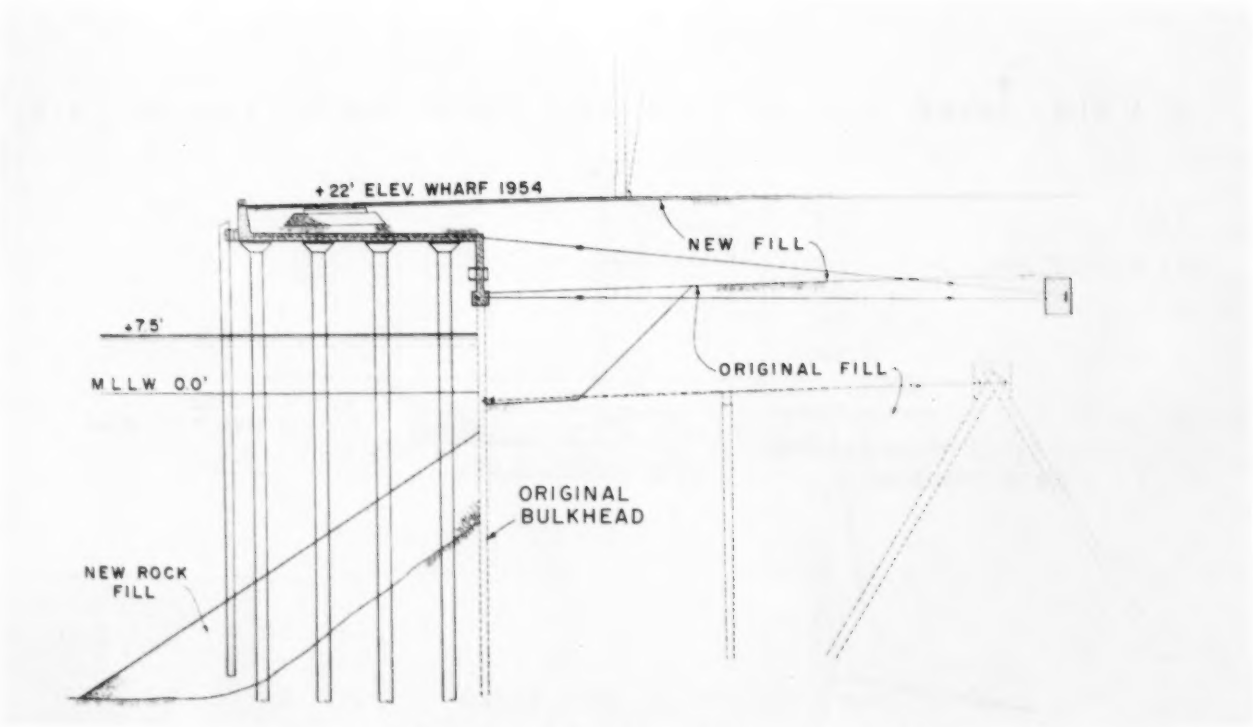

FIG. 17. CONCRETE CAP - PIERS B & C.

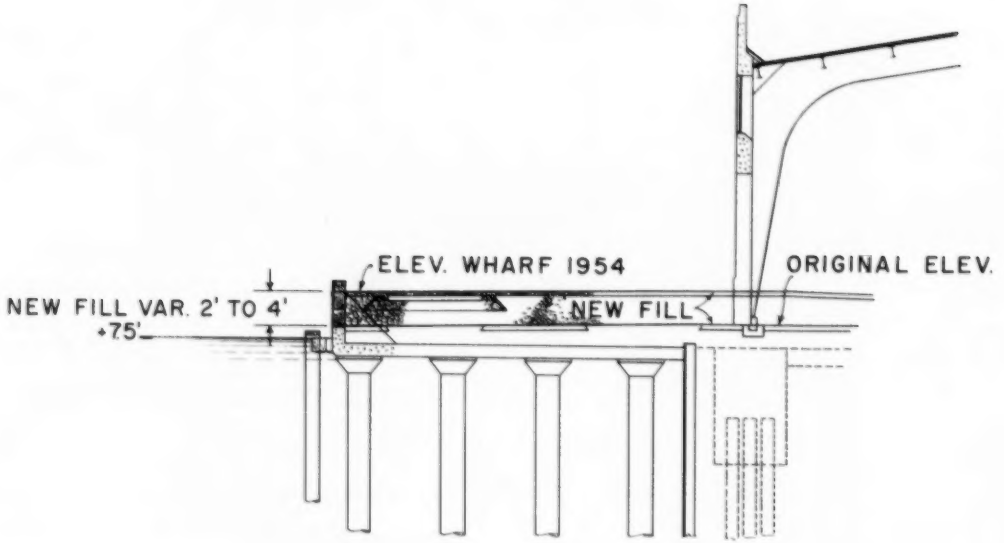

FIG. 18. RETAINING WALL FOR 2 FT. TO 4 FT. RAISE - PIER A.

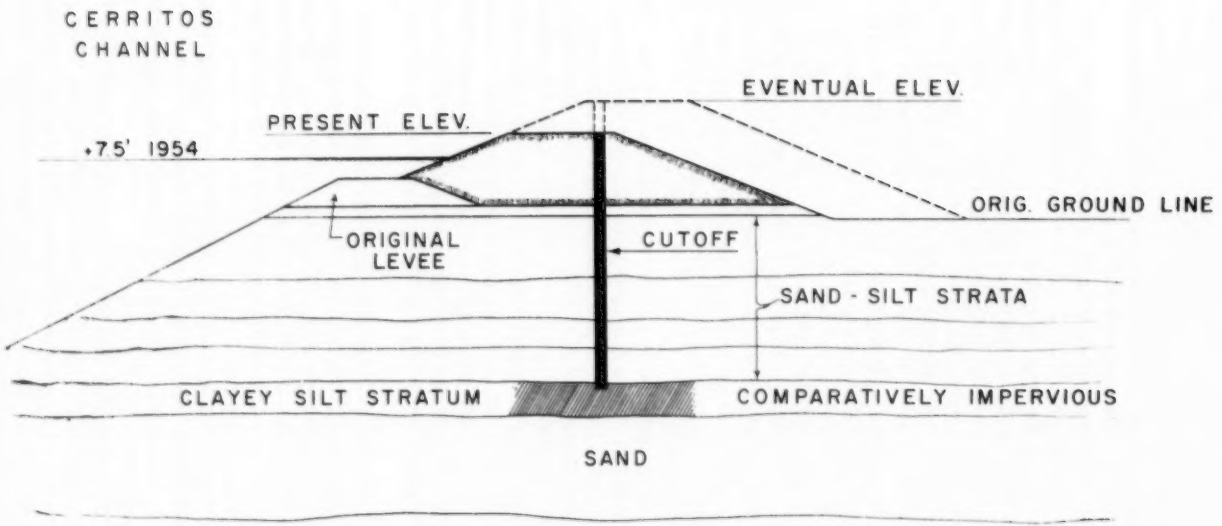

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FIG. 19. SECTION THRU CLAY CUTOFF LEVEE.
TERMINAL ISLAND.

dollar investment is high, this procedure either becomes less feasible, or, if indicated as ultimately essential, it becomes a slow process requiring years to accomplish. In the latter case, it is usually found that with the exception of oil wells and their accessories and a limited few buildings, all surface improvements must be abandoned. Because of future ground water tables in presently dry fills which will permeate new fills as the area subsides, essentially all abandoned facilities must be removed or rendered harmless by some positive step, such as plugging of abandoned utility lines.

4. Raising the elevation of valuable structures poses the question of economic justification. The answers of course vary. Due to rapidly changing technology and relative costs, it is usually more economical to rehabilitate with an entirely different form of construction, and, fortunately, this new form of construction usually permits greater load carrying capacity, greater safety, elimination of fire hazards and longer life. Not the least of the reasons for these results is the necessity for so designing the structure that it or its surroundings can be raised in the future or that it can be subjected to increased loads in the future. The transition of bulkheads from one stage to another is most likely to result in unique designs, of which there are a number.

5. Horizontal and vertical movements have required the raising and replumbing of the stationary parts of movable bridges. A retract barge bridge had its fixed features raised. A single leaf bascule was raised and will require a second raising. Relief measures have been taken on a vertical lift bridge where towers have not only experienced differential settlement, but have also been forced closer together, twisted and tilted out of plumb. These relief measures will be repeated.

6. Storm drains have often completely reversed direction of flow. This fact imposes unusual remedies. Some storm drains become sources of ocean flooding and must be abandoned. During the interim periods tidewater is sometimes diverted through manholes and street gutters to a different gravity drainage system. In early stages Calco gates were effective at the ocean ends.

7. Sewers are usually crushed or joints parted. The most important storm drain in the area is an abandoned 48-inch sanitary sewer which receives most of the ground water flow through its fractured laterals and conveys them to a pumping station originally constructed to handle sewage. In isolated cases sewage is now handled by septic tank. Those sewers serving important structures are repaired.

8. Steel and cast iron pipe lines generally fail from time to time by reason of the induced stresses from earth movements. In new installations, as well as in repairs, the maximum flexibility is designed into the lines. Breaks may be tensile failures, buckling or marked horizontal offsets which are usually bridged by flexible couplings or contractable connections. These failures can rarely be predicted as to exact position.

9. Railroad tracks have buckled even though designed for normal expansion. Relief can be quickly provided by cutting the buckled section.

10. Extremely massive undergound reinforced concrete conduits have failed. Replacements are above ground where practicable.

11. Major buildings, well equipped with contraction joints for normal conditions, have required adjustment to meet horizontal movements. One building structure, 120 feet by 832 feet, shortened some 12-3/4 inches on one side and a lesser degree on the other. Remedial work followed failure of the weakest panel in the building, and took the form of cutting a strip from the building for its full width and partially re-plumbing the two halves before reconnecting the severed parts. Early 1955 brought more shortening and

crushing failure to this same building. New structures are designed to accommodate these movements. The principle used is that of fixing dimensions so that anticipated forces will not result in undue stress.

12. Where possible, large buildings which have been subjected to unusual lateral forces will not be repaired or remedied until the structures are elevated, when locked up stresses induced from the footing connections will be released. Buildings are watched with care to observe possible sources of hazard.

13. Street grades are often seriously affected, so that surface water flows are reversed. As ground water tables approach subgrade, which they do despite use of pumping systems, streets and tracks are adversely affected.

14. Basically, any combination of structures in contact with the earth which have radically different elastic qualities will be differently affected. For example, a concrete gutter will be stressed to the point of tilting manholes or catch basins, whereas the asphaltic concrete adjacent will flow around obstructions.

15. Obviously, many forms of continuous structures are presently impracticable in the area and the principles of continuity must be carefully applied.

This outline of forms of remedial work is only sketchy. Hundreds of individual projects are involved. The work requires coordination, which is effected largely through the Engineering Division of the Port of Long Beach. Coordination of a much higher degree will be involved in the future. In some instances the diversity of ownerships indicate that coordination may not be feasible within the allotted time limits even for surface effects.

Pressure Maintenance as a Corrective Measure

Most important coordination will be that necessary to finally exercise control of gas, oil and water production in all producing zones. The need for maintaining pressures or of reestablishing virgin pressures to some degree in certain of the oil zones is already well established from the point of view of increasing total production of hydrocarbons.

The need for careful control of sources of injection water for such purposes in order to avoid further local differential subsidence effects is rather obvious.

In theory, pressure maintenance or repressuring will be an important step in reducing the total amount of or at least the rate of subsidence. In practice, however, it can reasonably be said that no such effort has ever been exerted for the purpose and certainly no results are on record. Such a step will require a number of years to accomplish.

It is as yet a somewhat undetermined matter as to what surface damage might ultimately be avoided by a pressure maintenance program as the time and economics of the program are unknown. Since the degree to which the true mechanics of the consolidation and compaction processes are known still leaves much to be desired, it follows that the total amount of and the timing of the subsidence is not yet accurately predicted. For this reason pressure maintenance studies and action are highly desirable, as they might be of considerable value in reducing subsidence in some of the fringe areas.

Subsidence Economics

The overall economic practicality of undertaking surface remedial measures is proven without question, although isolated cases present less attractive

pictures economically. The reason for this overall finding is based upon the high value of the facilities involved and their importance to the entire west. Compared with the economic advantages to the public and the gross income of the area, subsidence remedial costs are reasonable. Taken less objectively, the costs are very high.

Two years ago the author estimated the total cost at 120 million dollars, of which one-third had been expended. Currently his estimates would be substantially higher in view of recent predictions on subsidence. The Port engineering division has carefully estimated future foreseeable essential construction work on public harbor properties at 115 million dollars, of which the minimum estimated subsidence portions are about 63 million dollars. Since most of the remedial works necessarily combine additions and betterments, the final determination of subsidence cost becomes one of engineering and accounting analysis.

CONCLUSIONS

The overall corrective measures, while an economic burden, are nevertheless essential to the continued functioning of a number of very important public services.

The problems of surface corrective measures are being met readily by private and public agencies alike, but must be well coordinated and require heavy financing. The predictions of total ultimate subsidence and its timing are still subject to considerable variation.

To date there is no assurance of corrective measures being taken below the surface in time to be of important benefit.

Continued and accelerated examination into the mechanics of subsidence and the possibility of subsurface remedies is not only very important, but is fully justified on the basis of experience elsewhere in increased oil recovery.

PROCEEDINGS PAPERS

The technical papers published in the past year are presented below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. For titles and order coupons, refer to the appropriate issue of "Civil Engineering" or write for a cumulative price list.

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SEPTEMBER: 484(ST), 485(ST), 486(ST), 487(CP)[c], 488(ST)[c], 489(HY), 490(HY), 491(HY)[c], 492(SA), 493(SA), 494(SA), 495(SA), 496(SA), 497(SA), 498(SA), 499(HW), 500(HW), 501(HW)[c], 502(WW), 503(WW), 504(WW)[c], 505(CO), 506(CO)[c], 507(CP), 508(CP), 509(CP), 510(CP), 511(CP).

OCTOBER: 512(SM), 513(SM), 514(SM), 515(SM), 516(SM), 517(PO), 518(SM)[c], 519(IR), 520(IR), 521(IR), 522(IR)[c], 523(AT)[c] 524(SU), 525(SU)[c], 526(EM), 527(EM), 528(EM), 529(EM), 530(EM)[c], 531(EM), 532(EM)[c], 533(PO).

NOVEMBER: 534(HY), 535(HY), 536(HY), 537(HY), 538(HY)[c], 539(ST), 540(ST), 541(ST), 542(ST), 543(ST), 544(ST), 545(SA), 546(SA), 547(SA), 548(SM), 549(SM), 550(SM), 551(SM), 552(SA), 553(SM)[c], 554(SA), 555(SA), 556(SA), 557(SA).

DECEMBER: 558(ST), 559(ST), 560(ST), 561(ST), 562(ST), 563(ST)[c], 564(HY), 565(HY), 566(HY), 567(HY), 568(HY)[c], 569(SM), 570(SM), 571(SM), 572(SM)[c], 573(SM)[c], 574(SU), 575(SU), 576(SU), 577(SU), 578(HY), 579(ST), 580(SU), 581(SU), 582(Index).

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FEBRUARY: 608(WW), 609(WW), 610(WW), 611(WW), 612(WW), 613(WW), 614(WW), 615(WW), 616(WW), 617(IR), 618(IR), 619(IR), 620(IR), 621(IR)[c], 622(IR), 623(IR), 624(HY)[c], 625(HY), 626(HY), 627(HY), 628(HY), 629(HY), 630(HY), 631(HY), 632(CO), 633(CO).

MARCH: 634(PO), 635(PO), 636(PO), 637(PO), 638(PO), 639(PO), 640(PO), 641(PO)[c], 642(SA), 643(SA), 644(SA), 645(SA), 646(SA), 647(SA)[c], 648(ST), 649(ST), 650(ST), 651(ST), 652(ST), 653(ST), 654(ST)[c], 655(SA), 656(SM)[c], 657(SM)[c], 658(SM)[c].

APRIL: 659(ST), 660(ST), 661(ST)[c], 662(ST), 663(ST), 664(ST)[c], 665(HY)[c], 666(HY), 667(HY), 668(HY), 669(HY), 670(EM), 671(EM), 672(EM), 673(EM), 674(EM), 675(EM), 676(EM), 677(EM), 678(HY).

MAY: 679(ST), 680(ST), 681(ST), 682(ST)[c], 683(ST), 684(ST), 685(SA), 686(SA), 687(SA), 688(SA), 689(SA)[c], 690(EM), 691(EM), 692(EM), 693(EM), 694(EM), 695(EM), 696(PO), 697(PO), 698(SA), 699(PO)[c], 700(PO), 701(ST)[c].

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c. Discussion of several papers, grouped by Divisions.

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